IPM and ISM Coherence and Polarization E

by

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Although the opacity of the external medium would not be a problem for such an array, other effects need to be considered. Natural and artificial terrestrial emission would be a severe problem in low earth orbit (Erickson 1988, Erickson 1990, Desch 1990). As a result, high earth orbits (Mahoney *et al* 1987), heliocentric orbits (Jones *et al* 1995), and lunar locations (Smith 1990, Kuiper *et al* 1990) have been proposed . These concepts involve observing frequencies ranging from approximately 300 kHz to 30 MHz. Irregularities in the electron density of the IPM (Dennison *et al* 1988, Spangler & Armstrong 1990, Dennison & Booth 1987, Ananthakrishnan & Dennison 1990) and the Interstellar Medium (ISM) (Ricket et al 1984, Cordes et al 1984, Cordes et al 1985, Rickett 1986) will affect observations by a low frequency space array. The most obvious effect is the angular broadening caused by both media. This broadening limits the maximum useful baselines in the frequency range of interest to $\sim$ 100 km. Calculations of additional effects are presented below. Section 2 describes the media effects on temporal coherence, and Section 3 presents the effects on linear polarization.

Section 2. COHERENCE

Because of random and time-variable phase variations in the interplanetary medium, the coherence of observations with an interferometer will decrease with increasing integration time. This loss of temporal coherence is distinct from the loss of spatial coherence which results from the angular broadening mentioned above. Temporal coherence can be a problem even with baseline lengths too small to resolve the scattered source size. Low temporal coherence values (significantly less than 1.0) result in loss of sensitivity. They

$v_w \approx 350$ 1{111/s, with the irregularities formed near the sun and then propogated outward in a spherically diverging flow. '1'11(! structure constant C_n can be derived from power spectral density measurements (Armstrong et al 1979), giving, for typical IPM conditions:

$$C_n = \frac{2.8 \times 10^{-4}}{R^2 \nu_{\mathrm{MHz}}^2} \text{ A.U.}^{-1/3} \tag{4}$$

Here R is the distance from the sun in A11. and ν_{MHz} is the observing frequency, in MHz.

We can relate D_ϕ to D_n via

$$D_\phi(t) = \left\langle \left| \begin{array}{l} \int_0^\infty \left(N\left[\vec{x} + \vec{r}(s)\right] - N\left[\vec{x} + \vec{B} + \vec{r}(s)\right]\right) ds \\ - \int_0^\infty \left(N\left[\vec{x} + \vec{v}_w t + \vec{r}(s)\right] - N\left[\vec{x} + \vec{v}_w t + \vec{B} + \vec{r}(s)\right]\right) ds \end{array} \right|^2 \right\rangle \tag{5}$$

$\vec{r}(s)$ is the vector in the source direction at a distance s from the telescope location $\vec{x}$, $\vec{B}$ is the interferometer baseline, and $\vec{v}_w$ is the solar wind velocity. We expand eq.(5), exchange the order of integration and ensemble averaging, and make use of the relation

((i)

$$\langle N(\vec{x}_1) N(\vec{x}_2) \rangle = \langle N^2(\vec{x}) \rangle - \frac{1}{2} D_n\left(|\vec{x}_1 - \vec{x}_2|\right)$$

$D_\phi(t)$ can then be expressed as a sum of integrals of D_n, and these can be evaluated numerically. It(].((i) is only approximately valid because the diverging solar wind flow makes $\langle N^2 \rangle$ a function of position. However, over the baseline sizes and integration times (< 1 minute) of interest in this case, the effect of this approximation is negligible. A second approximation is introduced because eq.(1) is strictly valid only for a Gaussian distribution of baseline phases, and a Kolmogorov distribution is non-Gaussian. The third approx case (especially for the lower frequencies). The source size of (x].(7) at the galactic pole ($b = 90°$) was used, with a uniform intensity profile out to a shiii'j) cutoff. The choice of $b = 90°$ gave the minimum scattering size; any other galactic latitude would result in more effective averaging of phase fluctuations, and therefore a larger coherence than the value for $b = 90°$. The baseline was assumed to lie at a 45° angle to the radial solar wind flow direction, and an ecliptic latitude of 30° (21 c latitude for the 30° sun-source angle case) was chosen. Baseline lengths < J 00 km were used in cases where a source scattered by the ISM and IPM would be resolved on a 100 km baseline for the frequency and sun-source angle used.

The coherence for an unscattered point source is also shown in Table 1. *The true coherence* (corrected for the effects of scattering) *is much higher in all cases, and is close to 1.0 for a wide range of observing parameters.* The improvement over the point source case is most dramatic for low frequencies and short baselines, because $\theta_s(ISM) \cdot 1$ A.U. >> B for that regime. For sources which are resolved by the array, the appropriate size θ for calculating coherence is the synthesized beam size, $\theta_{beam} \approx \lambda/B$. For all the 10 MHz and 30 MHz cases in Table 1, $\theta_{beam} > \theta_s(ISM)$. Therefore, the coherence for resolved sources at these frequencies will be larger than the values in column 5 of Table 1.

$$\theta_s(IPM) \approx 0.023'' \lambda_m^2 \left(\frac{\psi}{90°}\right)^{-2}$$

Here ψ is the sun-source angle. $\theta_s(ISM) > \theta_s(IPM)$ when

$$\psi > 110° \, (\sin b)^{0.25}$$

$D_R(\vec{B})$ will be equal to $D_\phi(\vec{B})$, scaled by a factor that depends on H and λ. The result, for an IPM magnetic field of $H = 30$ microGauss, is:

$$(10) \quad \sqrt{D_R(B)} \approx \begin{cases} 3 \times 10^{-3} \left(\frac{B}{100 \text{ km}}\right)^{5/6} \left(\frac{\nu}{1 \text{ MHz}}\right)^{-2} & \text{radians at } 30^\circ \text{ sun - source angle} \\ 7 \times 10^{-4} \left(\frac{B}{100 \text{ km}}\right)^{5/6} \left(\frac{\nu}{1 \text{ MHz}}\right)^{-2} & \text{radians at } 90^\circ \text{ sun - source angle} \end{cases}$$

The ISM phase structure function does not exceed that of the IPM, except for large sun-source angles (eq. 8). Furthermore, the magnetic field is a factor ~ 30 weaker in the ISM. Therefore, $D_R(B)_{ISM}$ is smaller than $D_R(B)_{IPM}$ in most cases, and eq. (10) will be correct within a factor of a few when the effect of the ISM is added. Differential Faraday rotation across the baseline will be negligible, except possibly for observations in the galactic plane at the lowest frequencies.

A separate issue is angular Faraday depolarization across a source (or across a synthesized beam if the source is resolved). In this case, the effect of the ISM will be much larger than for the IPM, because the transverse dimension covered by the source in the ISM will be *much* larger. The Faraday angular depolarization factor F (the ratio of the observed fractional linear polarization to the polarization as emitted by the source) for a solid angle Ω will be:

$$(11) \qquad \left\langle F^2 \right\rangle = \frac{1}{\Omega^2} \int_{\Omega'} \int_{\Omega''} e^{-iD_R(\hat{s},\hat{s}')/2} d\Omega' \, d\Omega''$$

$$D_R(\hat{s}, \hat{s}') = \left\langle [R(\hat{s}) - R(\hat{s}')]^2 \right\rangle$$

$R(\hat{s})$ and $R(\hat{s}')$ are the Faraday rotations in the directions $\hat{s}$ and $\hat{s}'$, and the integrations are over the solid angle of the (scattered) source. The structure function $D_n(r)$ for the ISM was derived from $\theta_s(ISM)$ (eq. 7) and the assumption of a Kolmogorov spectrum. A path length for the scattering medium of 400 pc/ $\sin b$ was assumed (Rickett, 1977), and a uniform magnetic field of $H = 1$ microGauss was used. Calculated values of F $\left(F = \sqrt{\langle F^2 \rangle}\right)$ are presented in Table 2.

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TABLE 2. Expected Faraday Angular Depolarization

Observing Frequency	F over 1 Synthesized Beam (b = 90°)	F over 1 Synthesized Beam (b = 30°)	F over $\theta_s(ISM)$ at b = 90°	F over $\theta_s(ISM)$ at b = 30°
1 MHz	<0.001	<0.001	<0.001	<0.001
3 MHz	<0.001	<0.001	<0.001	<0.001
10 MHz	0.005	<0.001	0.11	0.06
20 MHz	0.3	0.08	0.9	0.5
30 MHz	0.8	0.4	1.0	0.9